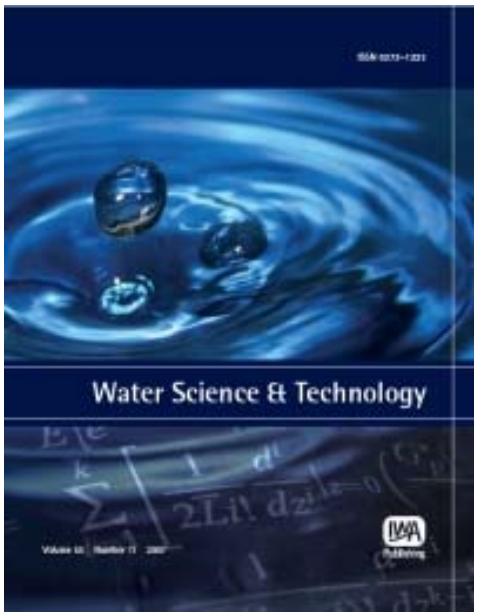

Performance assessment of AS-SBR and UF-MBR for hotel wastewater treatment

G. Libralato, A. Volpi Ghirardini and F. Avezzù

ABSTRACT

A large number of tourist structures in Venice (Italy) have small sized on-site treatment systems for their wastewater. Due to its historical characteristics, the city has no public sewerage system and untreated hotel wastewater represents a serious hazard for its lagoon environment. This study focused on the wastewater facilities installed in two hotels adopting an Activated Sludge Sequencing Batch Reactor (AS-SBR) and an Ultra-Filtration Membrane Biological Reactor (UF-MBR). Their performance was checked in terms of both traditional physico-chemical and ecotoxicological parameters, the importance of which has recently been recognised by EU regulatory dispositions and OSPAR indications. Acute and sub-chronic endpoints were both considered on a whole effluent toxicity basis by means of *Vibrio fischeri* and *Crassostrea gigas*, respectively. The two months monitoring survey evidenced that the UF-MBR was more efficient than the AS-SBR in providing high-quality discharges under both chemical and ecotoxicological viewpoints.

Key words | AS-SBR, bioassay, hotel wastewater, saltwater organisms, UF-MBR, WET

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INTRODUCTION

Many commercial and tourist-related activities in Venice (Italy), such as hotels, use small sized on-site treatment systems for their wastewater. Due to its peculiar historical characteristics, Venice has no public sewerage system and untreated wastewater represents a serious hazard for its lagoon environment. Indeed, the local and national law-makers decided to support the installation of small plants on a decentralised basis to intercept wastewater at source and facilitate on-site treatment in order to reduce and progressively eliminate most of the discharges. Scientists, governmental and non-governmental organisations are still debating about the role of decentralisation. Primarily, results evidenced its leading role in specific economic, social and environmental contexts, especially in relation to micropollutants removal and water reuse (Maurer *et al.* 2006).

A recent monitoring survey in Venice found, besides the presence of 5,447 discharges, also 4,493 wastewater treatment plants (WWTPs), partially remote-controlled, 65 of which were Activated Sludge Sequencing Batch Reactors (AS-SBR) and 43 Ultra-Filtration Membrane Biological Reactors (UF-MBR) (MAV 2007), with most of the others being septic tanks.

This study focused on the capacity of two WWTPs installed in two Venice four-star hotels using AS-SBR and UF-MBR technologies to provide good quality effluents with reduced toxicity. Hotel wastewater can be a serious hazard for the receiving environment as it contains a wide variety of contaminants ranging from personal care products and detergent metabolites to, potentially, some industrial chemicals and priority substances (Nakajima *et al.* 1999; Cobacho *et al.* 2005; Baumgarten *et al.* 2006). The WWTPs performance was checked considering both physico-chemical and ecotoxicological parameters on an end-of-pipe basis. Whole effluent toxicity (WET) testing was

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used for the identification of wastewater potential hazards to the receiving environment (USEPA 2004) as was the Whole Effluent Assessment (WEA) approach (OSPAR 2000, 2005). The bioluminescence inhibition test with *Vibrio fischeri* and the embryo-larval development test with *Crassostrea gigas*, because of their sensitivity and widespread use (OSPAR 2000, 2005), were used to check the toxicity removal efficiency, technological viability and reliability of the selected WWTPs.

MATERIALS AND METHODS

AS-SBR and UF-MBR technologies

In recent years, the AS-SBR technology has received increasing attention worldwide. Many full-scale plants have been built (Kazmi & Furumai 2000) and it has been accepted as an alternative to more conventional activated sludge systems for a wide range of industrial and non toxic biodegradable wastewater treatments (Wilderer *et al.* 2001).

The considered time-oriented AS-SBR, as shown in Figure 1, operates sequentially on a five serial steps basis (i.e. feed, mixing, aerobic reaction, settling and drawing) via two parallel reaction basins (A and B). Denitrification takes place during the feed and mixing period, while carbonaceous BOD removal and nitrification occur in the following oxidation stage. In addition, endogenous denitrification should take place during the settling phase. All the main characteristics of AS-SBR are provided in Table 1.

The UF-MBR is a newer technology for providing high quality effluents that has already been classified as Best Available Technology (BAT) by IPPC (2003) for its physico-chemical performance and potential for retrofitting existing WWTPs. In the UF-MBR, which is a development of the conventional activated sludge process, the secondary clarifier is replaced by a UF membrane filtration system (Stephenson *et al.* 2000). This membrane process has three main streams: a feed, retentate (unpermeated product) and permeate. The permeate discharged from UF-MBR plants with further treatments, if requested, could cover a range of reuse applications such as irrigation (agriculture and landscape), recreation and environmental, non-potable urban use, groundwater recharge, industrial use and indirect potable reuse. In these cases, nanofiltration or reverse osmosis could be viable tools to increase the quality of water resource (Fane & Fane 2005).

The considered cross flow side-stream UF-MBR, as indicated in Figure 2, is characterised by an aeration basin and a UF filtration unit that provide both the retentate and the permeate that are re-circulated in the aeration basin and discharged into the Venice Lagoon without any further treatment, in that order. All the main UF-MBR characteristics are provided in Table 2.

Sample handling, preservation and storage

NPDES general guidelines were followed for sampling and sample handling (USEPA 2004). Well mixed influent samples were manually collected from the WWTP feed tanks, whereas effluent samples were obtained after the final treatment and downstream from all entering wastewaters before the final discharge. Every sample was the result of 3 grab samples collected over a period of time not exceeding 8 h and homogenised to obtain a composite sample in order to reduce the variability of the wastewater characteristics according to a time composite sampling procedure. When taking samples, the collection of large

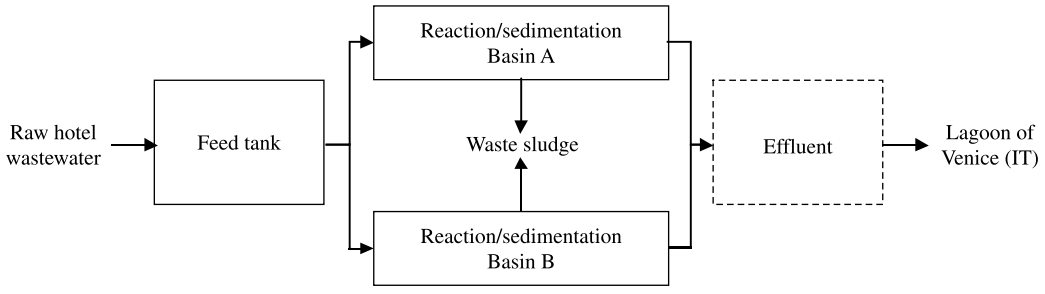

Figure 1 | Flow chart of the AS-SBR plant for hotel wastewater treatment.

Table 1 | AS-SBR main characteristics

Specification	Units	Values
Basin area	m^2	33 + 33
Minimum volume	m^3	41
Maximum volume	m^3	47
Working volume	m^3	42
HRT	h	24
Q	m^3/day	≈120
MLSS	g/L	6–8
MLSS/MLVSS		0.70–0.80
Operating temperature	°C	15–25
Remote control		Yes

and non-homogeneous particles or objects was avoided. Containers were completely filled, leaving no air space between the contents and the lid. A sufficient volume to allow for quality assurance testing (at least 1 L per grab sample) was collected. Once in the laboratory, discrete samples were mixed to produce composite samples. Sample aliquots were not further processed and stored at 4°C. ± 1°C until being characterised within 24 h to 36 h after collecting. Sample salinity was adjusted for ecotoxicological analyses.

The collection period lasted 2 months during springtime, doing weekly sampling for both AS-SBR and UF-MBR, for a total of 16 samples (influent and effluent) per WWTP.

Physical and chemical analysis

pH was measured with a pHmeter HI 9025 Microcomputer from HANNA Instrument®. The Chemical Oxygen Demand (COD) was determined according to 5130 procedure (APAT *et al.* 2003), N-NH_4^+ according to 4030/C (APAT *et al.* 2003) procedure, while N-NH_3 was calculated as a function of temperature and pH (USEPA 2002), Suspended Solids (SS) according to 2090 procedure and Total Kjeldahl Nitrogen (TKN) according to 5030 procedure (APAT *et al.* 2003). Anions (chloride, nitrite, nitrate, sulphate and phosphate) were determined by ion chromatograph system after filtering at 0.45 μm (Metrohm 761 Compact IC, column Metrohm Metrosep A Supp 5 150 × 4 mm). Salinity was checked with a refractometer and Dissolved Oxygen (DO) by a WTW (Nova Analytics) multiparametric device.

Ecotoxicological analysis and procedures

The ecotoxicity of samples was determined according to the acute test with *Vibrio fischeri* (Microtox® test) and the sub-chronic bioassay with *Crassostrea gigas*.

Microtox® tests were performed using Gram-negative marine bioluminescent bacteria NRRL-B-11177 (Lot 5B6036). The 100% protocol was followed according to Azur Environmental (1998) through Microtox® Model 500 Test System. This protocol allowed measurement of light outputs at a wavelength of 490 nm with readings after 5-, 15- and 30-min. time exposure at 15°C to samples serial dilutions. The light loss as a consequence of bacteria exposure to the toxic samples was the endpoint. Three replicates were performed for every sample dilution (12, 25, 50 and 100%), including the control (dilution water) and the reference toxicant.

The oysters for the embryotoxicity test were purchased ready to use from Guernsey Sea Farm Ltd (UK). The bioassay was performed in accordance with Libralato *et al.* (2007). All oyster bioassays were performed on a three replicates basis for every sample dilution, including the control and the reference toxicant, using sterile polystyrene

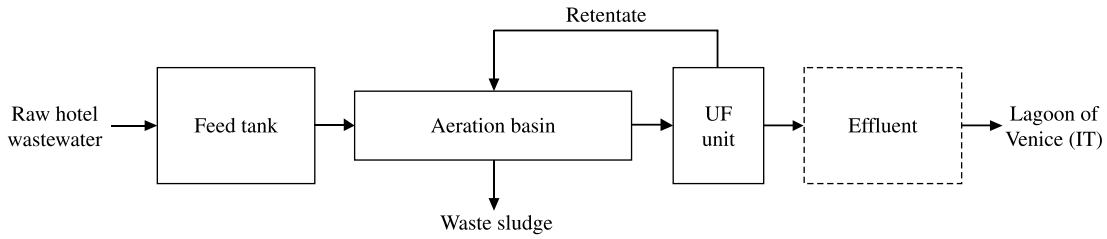

Figure 2 | Flow chart of the UF-MBR plant for hotel wastewater treatment.

Table 2 | UF-MBR main characteristics

Specification	Units	Values
Membrane characteristics		
Aeration basin area	m^2	76
Minimum volume	m^3	92
Maximum volume	m^3	107
Working volume	m^3	100
HRT	h	16
Q	m^3/day	150
MLSS	g/L	8–10
MLSS/MLVSS		0.75
Operating temperature	°C	18–30
Remote control		Yes
Materials		PVDF
Particles cut off	μm	0.12
Membrane brand and model		A19, PCI, UK
Membrane type		Tubular UF membrane module
Membrane configuration		16 + 16 modules in series–crossflow side-stream
Single module surface area	m^2	2.5
Effective membrane surface area	m^2	80
Operating pressures	kPa	$P_{IN} = 550 - P_{OUT} = 100$
Operating temperature range	°C	20–35
Module size	mm	3,600 length × 19 tubes × 12.5 diameter

24-well microplates with lids (Iwaki Brand, Asahi Techno Glass Corp.) as test chambers. Reconstituted artificial seawater was used throughout the experimental phase (ASTM 2004; Libralato *et al.* 2007).

Data analysis and interpretation

Dose-effect curves enabled the EC50 determination, which was transformed into Toxicity Units (TU50 = 100/EC50). Whenever EC50 was not quantifiable, the percentages of effect ≤ 50% (S), after Abbott's formula adjustment (ASTM 2004), were changed into TU50 considering TU50 = S/50. Prior to EC50 determination, all dilution concentrations were adjusted to the initial wastewater volume on the basis of a salinity adjustment procedure.

The bioluminescence inhibition values as EC50 were obtained by linear regression between wastewater concentration (as percentage) and the fraction of light loss to light remaining (Γ) on a logarithmic scale with 95% confidence limits. The data were considered acceptable when the correlation coefficient (R) showed values of 0.95 or greater and the reference toxicant was in line with the acceptability range (Azur Environmental 1998).

The oyster embryo toxicity EC50 values with relative 95% confidence limits were calculated by the Trimmed Spearman–Karber statistical method. The acceptability of test results was based on a negative control for a percentage of normal D-shape larvae ≥ 80% and on the response to the reference toxicant (Libralato *et al.* 2007).

In addition, toxicity data were transformed into Toxic Emission Factor (TEF) to obtain results normalised to effluent volume discharged per unit time (m^3/day) (Swedish EPA 1997). EC50 at 100% volume and 100 m^3/day flow rate corresponds to 100 TEF. TEF values lower than 100 are considered as acceptable (Swedish EPA 1997). Samples were also ranked according to Tonkes' classification system (Tonkes *et al.* 1999). Samples presenting EC50 < 1% volume are considered *very acutely toxic,*

1% ≤ EC50 < 10% volume *moderately acutely toxic*, 10% < EC50 ≤ 100% volume *minor acutely toxic* and EC50 > 100% volume *not acutely toxic*. The final effluent classification was based on the organism that showed the strongest response as in a worst case scenario basis.

RESULTS AND DISCUSSION

Physico-chemical data

A summary of AS-SBR and UF-MBR key results is presented in Table 3, considering lower, upper, average values and removal efficiency (%), expressed as the mean of single removal efficiencies.

AS-SBR and UF-MBR raw wastewater characteristics were shown to be similar. pH, DO and conductibility values remained constant over time, except for COD and SS, which presented higher values in UF-MBR influent (5 and 2 times, respectively). The UF-MBR displayed an excellent COD and SS removal, with 99% and 100% efficiency, respectively, as shown in Figure 3. Its performance did not change when the mixed liquor was partially recirculated in the feed tank because of a WWTP failure, generating COD influent hot spots of 3,040 mg/L, 13,652 mg/L and 3,120 mg/L. Conversely, AS-SBR presented a lower

Table 3 | Main physico-chemical results of hotel wastewater treatments for both AS-SBR and UF-MBR plants

Parameters	Units	AS-SBR			UF-MBR		
		i	e		i	e	
		Min-MAX average	Min-MAX average	Removal (%)	Min-MAX average	Min-MAX average	Removal (%)
pH		7.77–8.06	7.22–7.92	–	7.74–8.32	7.79–7.92	–
		7.80	7.60		7.80	7.90	
DO	mgO_2/L	1.70–2.50	1.30–1.90	–	1.16–2.11	1.39–2.05	–
		2.00	1.60		1.90	1.91	
Conductivity	μS/cm	659–836	891–1,110	–	629–999	1,010–1,301	–
		750	971		821	1,131	
COD	mgo_2/L	225–502	11–338	39	324–13,652*	4–11	99
		365	202		1,726	8	
TKN	mg/L	25–37	2–27	42	26–87	2–33	89
		34	18		50	9	
$N\text{-}NH_4^+$	mg/L	13–24	1–20	46	3–37	0.7–2.7	93
		20	12		21	2	
$N\text{-}NO_2^-$	mg/L	0.00–0.80	0.00–0.30	34	0.00–0.40	0.00–0.00	93
		0.01	0.00		0.01	0.00	
$N\text{-}NO_3^-$	mg/L	0.00–1.70	0–15	0	0.00–0.70	0.10–18.40	0
		0.04	3.00		0.01	6.03	
P_{TOT}	mg/L	3–6	2–6	4	4–44	4–5	59
		5	4		11	4	
$P\text{-}PO_4^-$	mg/L	0.7–9.9	1.3–2.8	0	1.6–35.0	3.0–4.8	32
		2.1	2.0		6.0	3.1	
$S\text{-}SO_4^-$	mg/L	2.60–12.10	3.50–11.50	9	7.40–13.90	10.30–15.90	2
		8.00	6.04		9.02	11.05	
SS	mg/L	112–216	6–272	41	60–688	0	100
		166	91		308		

*Mixed liquor recirculated in the feed tank.
i = influent, e = effluent.

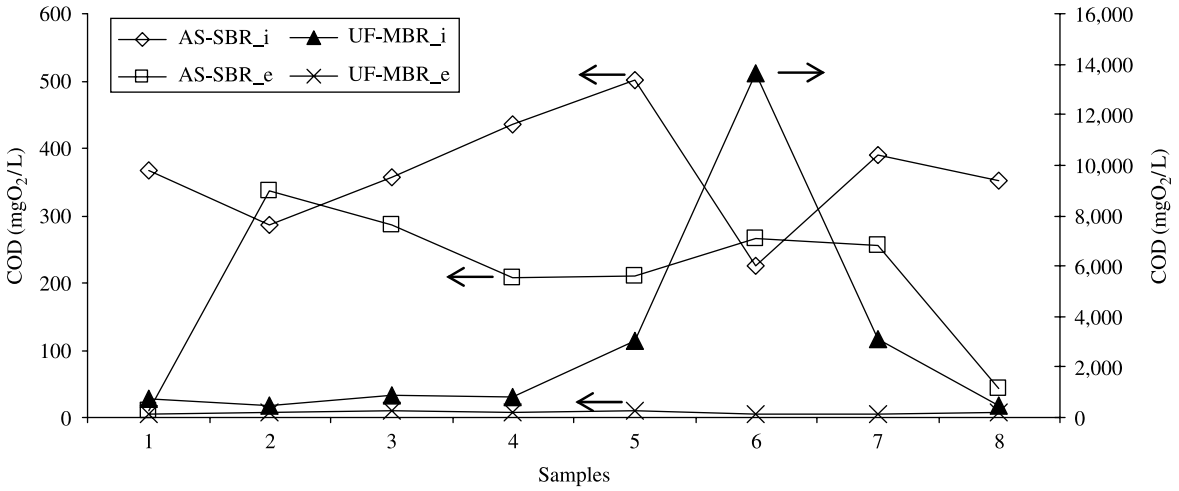

Figure 3 | COD trend in AS-SBR and UF-MBR; i = influent, e = effluent.

efficiency level for both COD and SS removal (39% and 41%). There were also higher removal rates of nitrogen as TKN, N-NH_4^+, N-NO_2^- in UF-MBR (89%, 93% and 93%) than in AS-SBR (42%, 46% and 34%). Nitrification processes were evidenced in both WWTPs, with a subsequent denitrification stage that ranged between 35% and 89% for AS-SBR, whereas it was 9%–48% for UF-MBR.

AS-SBR effluent maintained an average concentration of 3.00 mg/L of NO_3^-, while an average concentration of 11.03 mg/L of NO_3^- still remained in the UF-MBR permeate. Phosphorus reduction both as total P and P-PO_4^- once again highlighted that UF-MBR (59% and 32%) was more efficient than AS-SBR (4% and 0%).

Toxicity results

Toxicity tests negative and positive controls were all acceptable (Azur Environmental 1998; Libralato *et al.* 2007).

Raw and treated wastewater TU50 results are presented for both testing species in Table 4. Embryotoxicity with *C. gigas* showed raw wastewater toxicity values ranging from 16.33 TU50 to 59.52 TU50 for AS-SBR and from 17.18 TU50 to 54.05 TU50 for UF-MBR. *V. fischeri* evidenced toxicity values ranging from 1.42 TU50 to 3.35 TU50 (30-min.) for AS-SBR raw wastewater, while UF-MBR inflow presented similar *V. fischeri* toxicity levels from 1.16 TU50 to 3.70 TU50 (30-min.). Effluents discharged from UF-MBR highlighted slight or no toxic effects according to *C. gigas*. The slight toxicity was detected only for samples 1, 2 and 3, which resulted in a percentage of effect ≤ 10%. *V. fischeri* confirmed the presence of a slight toxicity effect in UF-MBR treated wastewater samples: sample 1 presented no toxic effects, but all others showed percentages of effect ≤ 43% (TU = 0.86). The UF-MBR facility evidenced the capacity to greatly reduce toxicity in all samples. *C. gigas* showed that UF-MBR removed the toxicity almost completely (about 99%). Moreover, at the same time *V. fischeri* showed toxicity reduction capacities ranging from 67% to 99% (30-min.).

In the AS-SBR discharges, *C. gigas* evidenced no toxic effects for sample 1, but all others demonstrated some toxicity effect from a minor to raw wastewater-like TU50 value, as shown by *V. fischeri*. Moreover for AS-SBR, *C. gigas* indicated discontinuous toxicity reduction efficiency ranging between 6% and 99%, on average much lower than that of UF-MBR. It frequently occurred that *V. fischeri* indicated some effluent samples as much more toxic than the relative inflow.

In general, the oyster embryotoxicity test was shown to be better able to discriminate between raw and treated wastewater than *V. fischeri*, which evidenced limits in detecting noticeable ecotoxicological dissimilarities in hotel wastewater and WWTPs efficiency.

Wastewater toxicities classified on the basis of Tonkes' score are given in Table 5A and B. Raw wastewater samples for both WWTPs according to *C. gigas* were all classified as *moderately acutely toxic*, while *V. fischeri* classified them all

Table 4 | Toxicity of influent and effluent samples as TU50 and relative 95% confidence limits; according to *C. gigas* and *V. fischeri* 30-min. bioassays

Samples	Toxicity (TU50)							
	AS-SBR				UF-MBR			
	C. gigas		*V. fischeri* 30-min		*C. gigas*		*V. fischeri* 30-min	
	i	e	i	e	i	e	i	e
1	29.67 (27.17–32.47)	No effect	1.46 (1.12–1.89)	0.04* (0.00–0.09)	36.23 (34.25–38.31)	0.20* (0.18–0.22)	2.95 (2.64–3.29)	No effect
2	16.33 (15.75–16.95)	4.93 (4.34–5.59)	2.30 (2.01–2.63)	2.15 (1.79–2.62)	36.10 (33.67–38.76)	0.14* (0.12–0.16)	3.70 (3.36–4.06)	0.86* (0.82–0.90)
3	24.21 (22.12–26.46)	17.83 (16.84–18.87)	3.00 (2.78–3.25)	1.32 (0.76–2.27)	32.57 (30.49–34.84)	0.06* (0.02–0.10)	2.39 (2.14–2.66)	0.36* (0.32–0.40)
4	38.76 (35.34–42.37)	13.87 (12.89–14.90)	1.82 (1.56–2.12)	3.12 (2.64–3.68)	17.18 (16.23–18.18)	No effect	2.53 (2.06–3.11)	0.60* (0.56–0.64)
5	47.85 (43.67–52.36)	44.44 (33.33–59.17)	1.42 (1.22–1.66)	2.21 (1.99–2.45)	48.78 (44.05–53.76)	No effect	1.51 (1.15–1.98)	0.34* (0.32–0.36)
6	49.50 (45.66–53.48)	44.64 (34.01–58.48)	3.14 (2.87–3.44)	4.08 (3.60–4.57)	24.88 (20.66–29.94)	No effect	1.54 (1.18–1.75)	0.34* (0.26–0.42)
7	48.78 (44.64–53.19)	45.66 (37.17–56.18)	1.84 (1.51–2.25)	2.32 (2.07–2.60)	34.48 (33.44–35.59)	No effect	1.50 (1.17–1.80)	0.38* (0.34–0.42)
8	59.12 (53.48–66.23)	1.04 (0.96–1.12)	3.35 (3.01–3.73)	No effect	54.05 (49.50–58.82)	No effect	1.16 (1.12–1.20)	0.48* (0.44–0.52)

*% of effect $<$ 50%.

Table 5 | Table 5A and B Tonkes' score classification system (1999) for *C. gigas* and *V. fischeri* 30-min. toxicities

Samples	AS-SBR		UF-MBR	
	i	e	i	e
A	*Tonkes' Score–C. gigas*			
1	Moderately acutely toxic	Not acutely toxic	Moderately acutely toxic	Not acutely toxic
2	Moderately acutely toxic	Minor acutely toxic	Moderately acutely toxic	Not acutely toxic
3	Moderately acutely toxic	Moderately acutely toxic	Moderately acutely toxic	Not acutely toxic
4	Moderately acutely toxic	Moderately acutely toxic	Moderately acutely toxic	Not acutely toxic
5	Moderately acutely toxic	Moderately acutely toxic	Moderately acutely toxic	Not acutely toxic
6	Moderately acutely toxic	Moderately acutely toxic	Moderately acutely toxic	Not acutely toxic
7	Moderately acutely toxic	Moderately acutely toxic	Moderately acutely toxic	Not acutely toxic
8	Moderately acutely toxic	Minor acutely toxic	Moderately acutely toxic	Not acutely toxic
B	*Tonkes' Score–V. fischeri 30-min*			
1	Minor acutely toxic	Not acutely toxic	Minor acutely toxic	Not acutely toxic
2	Minor acutely toxic	Minor acutely toxic	Minor acutely toxic	Not acutely toxic
3	Minor acutely toxic	Minor acutely toxic	Minor acutely toxic	Not acutely toxic
4	Minor acutely toxic	Minor acutely toxic	Minor acutely toxic	Not acutely toxic
5	Minor acutely toxic	Minor acutely toxic	Minor acutely toxic	Not acutely toxic
6	Minor acutely toxic	Minor acutely toxic	Minor acutely toxic	Not acutely toxic
7	Minor acutely toxic	Minor acutely toxic	Minor acutely toxic	Not acutely toxic
8	Minor acutely toxic	Not acutely toxic	Minor acutely toxic	Not acutely toxic

as *minor acutely toxic*, as a consequence of the testing species relative sensitivity. In AS-SBR, *C. gigas* classified 5 effluents as *moderately acutely toxic*, 2 as *minor acutely toxic* and 1 as *not acutely toxic*, while *V. fischeri* found 6 *minor acutely toxic* and 2 *not acutely toxic* samples (30-min.). In UF-MBR, all effluents according to both bioassays were classified as *not acutely toxic*, considering the fact that raw wastewater samples were all *moderately acutely toxic* for oysters and all *minor acutely toxic* for bacteria. The UF-MBR technology was thus able to significantly improve the quality of the discharge, reducing the effluent toxicity.

Wastewater toxicities classified on the basis of TEF ranking system are given in Table 6A and B for AS-SBR and UF-MBR, respectively. Similarly to Tonkes' score, TEF evidenced that all UF-MBR effluents according to both bioassays could be classified as *acceptable*, except for sample 2 as revealed by the 30-min *V. fischeri* test, which could anyway be considered as a borderline sample. On the

Table 6 | Table 6A and B Swedish EPA classification system (1997) for *C. gigas* and *V. fischeri* 30-min. toxicities

		Swedish EPA's Score															
	AS-SBR	i								e							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
A	*Bioassay*																
	C. gigas	NA	NA	NA	NA	NA	NA	NA	NA	A	NA	NA	NA	NA	NA	Na	NA
	V. fischeri 30-min	NA	NA	NA	NA	NA	NA	NA	NA	A	NA	NA	NA	NA	NA	NA	A
B	*UF-MBR*																
	C. gigas	NA	NA	NA	NA	NA	NA	NA	NA	A	A	A	A	A	A	A	A
	V. fischeri 30-min	NA	NA	NA	NA	NA	NA	NA	Na	A	NA	A	A	A	A	A	A

A = Acceptable, NA = Not Acceptable.

contrary, just one AS-SBR treated wastewater could be accepted for discharge (Swedish EPA 1997).

In conclusion, the UF-MBR technology showed better efficiency in toxicity reduction, suggesting its adequacy in hotel wastewater treatment. In particular, it greatly enhanced discharge quality, satisfying Tonkes' score and TEF requirements for a nearly zero emission discharge (OSPAR 2000, 2005). On the contrary, the AS-SBR facility did not guarantee high or continuous wastewater treatment performance for either physico-chemical or ecotoxicological parameters.

CONCLUSIONS

This research assessed the reliability of AS-SBR and UF-MBR technologies in hotel wastewater treatment applied to small plants on a decentralised basis. The survey evidenced that the UF-MBR is more suitable for hotel wastewater treatment, providing high quality effluents not only from a physico-chemical viewpoint, such as for COD and SS, but also according to ecotoxicological results, as suggested by the low or no toxic effects of discharges checked via *C. gigas* and *V. fischeri* bioassays. Conversely, the AS-SBR showed that no high discharge quality levels could be assured, verifying the presence of a wide discontinuity in its performance.

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REFERENCES

APAT, IRSA and CNR. 2003 Analytical Methods for Waters. Report 29.

ASTM 2004 Standard Guide for Conducting Static Acute Toxicity Tests Starting with Embryos of Four Species of Saltwater Bivalve Molluscs. E724-1998/2004.

Azur Environmental 1998 Microtox Acute Toxicity Test Guide, Users manual.

Baumgarten, S., Schroder, H. F. & Pinnekamp, J. 2006 Performance of membrane bioreactors used for treatment of wastewater from the chemical and textile industries. *Water Sci. Technol.* **53**(3), 61–67.

Cobacho, R., Arregui, F., Parra, J. C. & Cabrera, E. 2005 Improving efficiency in water use and conservation in Spanish hotels. *Water Sci. Technol.: Water Supply* **5**(3), 273–279.

Fane, A. G. & Fane, S. A. 2005 The role of membrane technology in sustainable decentralised wastewater systems. *Water Sci. Technol.* **51**(10), 317–325.

IPPC 2003 Reference document on best available techniques in common waste water and waste gas treatment/management systems in the chemical sector. European Commission, February, 2003.

Kazmi, A. A. & Furumai, H. 2000 Field investigation on reactive settling in an intermittent aeration sequencing batch reactor activated sludge process. *Water Sci. Technol.* **41**(1), 127–135.

Libralato, G., Losso, C. & Volpi Ghirardini, A. 2007 Toxicity of untreated wood leachates towards two saltwater organisms (*Crassostrea gigas and Artemia franciscana*). *J. Hazard. Mater.* **144**, 590–593.

Maurer, M., Rothenberger, D. & Larsen, T. A. 2006 Decentralised wastewater treatment technologies from a national perspective: at what cost are they competitive? *Water Sci. Technol.: Water Supply* **5**(6), 145–154.

MAV 2007 Venezia, una scelta obbligata. I trattamenti individuali di depurazione. A cura di Ferrari, G., e Tromellini, E., Marsilio (eds). Venezia. *In Italian*.

Nakajima, J., Fujimura, Y. & Inamori, Y. 1999 Performance evaluation of on-site treatment facilities for wastewater from households, hotels and restaurants. *Water Sci. Technol.* **39**(8), 85–92.

OSPAR 2000 OSPAR Background Document concerning the Elaboration of Programmes and Measures relating to Whole Effluent Assessment.

OSPAR 2005 Whole Effluent Assessment. Publication 219.

Stephenson, T., Judd, S., Jefferson, B. & Brindle, K. 2000 *Membrane Bioreactors for Wastewater Treatment*. IWA Publishing, Padstow, Cornwall, UK.

Swedish EPA 1997 Characterisation of Discharges from Chemical Industry–The Stork Project. Swedish Environmental Protection Agency, Report 4766, Stockholm.

Tonkes, M., de Graaf, P. J. F. & Graansma, J. 1999 Assessment of complex industrial effluents in The Netherlands using a whole effluent toxicity (or WET) approach. *Water Sci. Technol.* **39**(10–11), 55–61.

USEPA 2002 Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. EPA 821-R-02-012, 5th edition.

USEPA 2004 NPDES Compliance Inspection Manual. EPA 305-X-03-004.

Wilderer, P. A., Irvine, R. & Goronszy, M. 2001 *Sequencing Batch Reactor Technology, Scientific and Technical Report 10*. IWA Publishing, London, UK.